Colour denotes viruses, fungi, parasites, Gram-positive and Gram-negative bacteria.

I: Community-acquired infections

Bacteria
Bacterial species come in lots of shapes and forms:

**Cocci**
- cocci
- diplococci
- diplococci encapsulated
- Staphylococci
- streptococci
- sacina
- tetrad

**Bacilli**
- coccobacillus
- bacillus
- diplobacilli
- palisades
- Streptobacilli

**Budding and appendaged bacteria**
- hypha
- stalk

**Others**
- enlarged rod
- Fusobacterium
- Vibrio
- Comma’s form
- Bdelovibrio
- Club Rod
- Corynebacteracea
- Helical form
- Helicobacter pylori
- Corkscrew’s form
- Borrelia burgdorferi
- Flamentous
- spirochete
Common bacterial virulence factors

- diverse secretion systems, so called as they move molecules towards the exterior of cells
- flagella, for movement and attachment
- pili (smaller, hair-like projections), for attachment
- capsule, for protection against phagocytosis e.g. *Streptococcus pneumoniae*
- endospores, metabolically dormant forms of bacteria, resistant to heat and cold, desiccation (dryness) and chemicals e.g. *Bacillus* sp. (species), *Clostridium* sp.
- biofilms, organised aggregates of bacteria embedded in a polysaccharide matrix which is antibiotic resistant e.g. *Pseudomonas aeruginosa*, *Staphylococcus epidermidis*

Exotoxins are proteins released as free molecules by bacteria:

- neurotoxins act on nerves or motor endplates e.g. *Clostridium tetani* or *C. botulinum* toxins
- enterotoxins act on the GI tract, either causing:
  - infectious diarrhoea, if bacteria are alive inside you e.g. *Campylobacter jejuni*, *Escherichia coli*, *Vibrio cholerae*, *Shigella dysenteriae*
  - food poisoning, if toxins the bacteria produced while in the food weren’t destroyed by cooking e.g. *Bacillus cereus*, *Staph. aureus*
- pyrogenic exotoxins stimulate release of cytokines, e.g. *Strep. pyogenes*, *Staph. aureus*
- tissue invasive exotoxins are enzymes allow bacteria to destroy and tunnel through tissue e.g. *Strep. pyogenes*, *Staph. aureus*, *Clostridium perfringens*
- unique or badly understood others exist e.g. *Bacillus anthracis*, *Corynebacterium diphtheriae*

Endotoxins can only be produced by Gram-negative bacteria, because they’re not free molecules but rather the lipid A moiety of lipopolysaccharides from bacterial outer membranes. They are shed steadily from living bacteria. Endotoxins are antigens that the immune system responds to to combat such bacteria. However, lysing the bacteria (e.g. with antibiotics) can cause sudden release of large quantities of endotoxin, thus worsening any septic shock.

Outbreaks

“An outbreak is a greater-than-normal or greater-than-expected number of individuals infected or diagnosed with a particular infection in a given period of time, or a particular place, or both.”

Good, timely reporting systems are instrumental for identifying outbreaks. After reporting, the cause of an outbreak must be confirmed and it must be ensured that there are no other causes.

Communicable diseases in Europe are split into 6 categories:

- respiratory tract infections
- sexually-transmitted infections, including blood-borne viruses
- food- and water-borne diseases and zoonoses
- emerging and vector-borne diseases
- vaccine-preventable diseases
- drug-resistance and healthcare-associated infections
Respiratory tract infections:
- **influenza**, including bird flu and swine flu
- **Mycobacterium tuberculosis** (called Gram-positive but has another lipid layer in its cell wall, making treatment difficult) can also become dormant, leading to ‘**latent** tuberculosis’ where immunological evidence of current infection exists without clinical signs or symptoms
- **Legionella pneumophilia** lives in ponds, lakes, and air conditioning units, and infects hosts via inhalation of contaminated aerosols. Its type IV secretion system then allows Legionella to survive and replicate in vacoles inside alveolar macrophages (causes **Legionnaires’ disease**)

Sexually-transmitted infections:
- **Chlamydia trachomatis** (chlamydia) is the most common STI in Europe. It is responsible for more than 3% of world blindness too, infecting tens of millions of people’s eyes. It is an obligate intracellular pathogen so cannot be cultured outside the host cells.
- **Neisseria gonorrhoeae** (gonorrhoea) establishes infection of the urogenital tract via non-ciliated epithelial cells. Important virulence factors are its pili and the antigenic variation that help it escape immune detection and clearance.
- **Treponema pallidum** (syphilis)
- hepatitis B and C viruses
- **HIV**

Food- and water-borne diseases and zoonoses:
- **Campylobacter** sp. (mostly **jejuni**) is the most commonly reported GI infection in the EU. Cases are usually sporadic rather than outbreaks, and tend to affect 0-4 year-olds. Undercooked poultry is the most likely source. It has many important virulence factors.
- **Salmonella** sp. also infects small children mostly via undercooked poultry, but outbreaks of it do occur. Type III secretion systems on pathogenicity islands are crucial virulence factors.
- **cholera** toxin (from **Vibrio cholerae**) causes upregulation of a Cl− channel (CFTR) in the GI epithelium, causing severe, acute dehydration. The most recent outbreak was in Haiti.
- **Listeria monocytogenes** can enter non-phagocytic cells and cross tight barriers, allowing it to penetrate the intestinal barrier, blood-brain barrier, and placenta. Listeria’s intra- and intercellular movement (which creates ‘**comet trails**’ of actin) is a popular research topic.
- **Escherichia coli**
- **Clostridium botulinum**
- **Shigella dysenteriae**
- **Bacillus anthracis**
- **typhoid fever**, caused by **Salmonella enterica enterica** of the serotype ‘typhi’.
- **parasites** such as **Giardia**, which causes **traveller’s diarrhoea** (giardasis)

Emerging and vector-borne diseases:
- **malaria**, caused by the **Plasmodium** parasite
- **plague**, caused by **Yersinia pestis** (there are three types of the plague, bubonic is just one)
- **SARS** (severe acute respiratory syndrome)
- **smallpox**
- **West Nile fever**
- **yellow fever**
Vaccine-preventable diseases:
- Corynebacterium diphtheriae (diphtheria)
- Clostridium tetani (tetanus)
- Bordetella pertussis (pertussis)
- Neisseria meningitidis (meningitis)
- Haemophilus influenzae
- measles
- mumps
- rubella
- poliomyelitis (polio)
- rabies

Drug-resistance and healthcare-associated infections: see next lecture.
2: **Hospital-acquired infections**

**Antimicrobial:** agent which interferes with growth and reproduction of a microbe  
**Antibacterial:** agent used to reduce or eliminate harmful bacteria  
**Antibiotic:** type of antimicrobial agent; originally referred to one of organic origin  

**Healthcare-associated infections (HAI)**s are infections that occur after exposure to healthcare. Infection **starts over 48 hours after admission**. Spread is very easy in hospitals, both via staff and when patients are moved between different wards or departments. The higher concentration of sick people also contributes to higher risk of infection in hospital. Infections often occur via interventions like catheters, intubation, and other prosthetic material. Prophylactic antibiotics can lead to drug-resistant infection. Every day in Europe, 1/18 patients in hospital acquires an HAI. They are usually:  
- surgical site infections  
- urinary tract infections  
- bloodstream infections  
- GI infections  
- pneumonia  

**The ESCAPE pathogens**

**Drug resistance** is a common feature of the **most important HAI**s (use the mnemonic **ESCAPE**):  
- **Enterococcus faecium**  
- **Staphylococcus aureus**  
- **Clostridium difficile**  
- **Acinetobacter baumanii**  
- **Pseudomonas aeruginosa**  
- **Enterobacteriaceae** family, including *E. coli*, **Klebsiella pneumoniae**, and **Enterobacter** sp.  

Pathogenic **E. coli** is the most frequent hospital-acquired cause of **Gram-negative bacteraemia**, and the most frequent cause of all **urinary tract infections** (UTIs). Recently, there has been an increase in drug-resistant strains. Some antibiotics that **E. coli** can show resistance to are:  
- **cephalosporins** are a class of β-lactam antibiotics that block peptidoglycan (PG) synthesis by inhibiting penicillin binding proteins (PBPs). Resistance is up to 20% in some countries, and the method is an **extended-spectrum β-lactamase** (ESβL) enzyme which cleaves the cephalosporin  
- **carbapenems** are another class of β-lactam antibiotics which inhibit the same pathway. Most cephalosporin-resistant strains are still sensitive to carbapenems. Resistance can develop through a carbapenemase enzyme (encoded on a transposon as opposed to ESβL’s plasmid)  

**K. pneumoniae** is an important cause of **UTIs** and **RTIs** in the **immunocompromised**. It is often cephalosporin and/or carbapenem resistant. **P. aeruginosa** also infects the immunocompromised, most notably battlefield trauma cases (though in that case the ‘healthcare-associated’ part is tenous).  

**MRSA** (methicillin-resistant **Staph. aureus**) is the **most common drug-resistant infection** worldwide. Methicillin is another β-lactam antibiotic, but resistance to it comes via expression of an additional PBP, one with a lower affinity for methicillin.  

**E. faecium** is **60% vancomycin-resistant**, as the bacterium synthesises a different PG precursor.
3: Immunity to fungal infections

Response to infection
Most fungi are destroyed within hours by innate defence mechanisms mediated by phagocytes and opsonins through the involvement of distinct pattern-recognition receptors (PRRs) which recognise PAMPs and DAMPs (pathogen/damage-associated molecular patterns). These mechanisms are followed hours later by an inflammatory response. These early phases help to keep infection under control.

If the infectious organism breaches these early lines of defence, an adaptive immune response will ensue, with the generation of antigen-specific $T_h$ cells, $T_{reg}$ cells and B cells that target the pathogen and induce memory cells that prevent subsequent infection with the same microorganism. Dendritic cells sample fungi at the site of colonisation, transport antigens to the draining lymph nodes and activate disparate $T_h$ and $T_{reg}$ cells in a morphotype- and tissue-dependent manner. Since different $T_h$ cell subsets release different cytokines, the activation of the appropriate $T_h$-cell subset is instrumental in the generation of a successful immune response. Regulatory $T_{reg}$ cells might serve to dampen excessive inflammation and contribute to the development of memory immunity.

Fungal morphisms
Species such as Candida show dimorphism (two forms, yeast buds or hyphae). Aspergillus is inhaled as conidia, but invades tissues as hyphae. The form of the fungus is also crucial to the host’s ability to compose an immune response. Cryptococcus neoformans’ capsule allows it to evade phagocytosis.

Antifungals
Tacrolimus has antifungal properties and also inhibits calcineurin and thus IL-2 secretion by T cells. Streptomyces tsukubaensis produces it.

Mycophenolate mofetil is another antifungal which inhibits lymphocyte proliferation. It’s also a mycotoxin, as it’s produced by a fungus: Penicillium brevicompactum.

Interferon-$\gamma$ enhances clearance of fungal infections by suppressing IL-10, allowing more inflammation.

N.B. This lecture’s slides were just study after study after study. ABS’ notes are much more extensive.
4: Viral evasion of the host immune system

Viruses are obligate intracellular parasites. A virus hijacks host cells’ production systems to replicate its genome (which can be DNA or RNA) and then produce the necessary proteins for more viral particles to be made, packaged, and released. Viruses are very diverse, and can be surrounded by a lipid envelope, protein capsid, or both, in various shapes. This is a generic replication cycle:

The 3 stages of defence are (as always): intrinsic defences, innate immunity and acquired immunity.

Interferon
Interferon (IFN) is a soluble cytokine secreted by infected cells, and a ‘master regulator’ of the immune response. PAMP recognition at the cell surface signals IFNβ transcription. IFN then has auto- and paracrine effects, signalling de novo transcription of interferon-stimulated genes (ISGs):
- PKR (protein kinase R) binds to viral DNA, preventing transcription, and activates NFkB
- 2’S’OAS (oligoadenylate synthetase) causes an RNase to cleave mRNA, preventing translation
- Mx, a GTPase, binds viral genomes to stop movement / action (e.g. Mx1 to flu, Mx2 to HIV)
- APOBEC3G deaminates dC to dU, causing G to A hypermutation in retroviruses (e.g. HIV)
- IFITM3 stops enveloped viruses’ (e.g. flu) genomes from entering the host cell nucleus
- (other genes which cause cell cycle arrest and apoptosis)

The IFN response can only be maintained for a few hours before it is overcome by negative regulation. Good, since IFN is toxic. SOCS (suppressors of cytokine signalling) are one thing which switch IFN off.
There are different types of IFN:
- **Type I** IFNs are IFNα and IFNβ. These can be secreted by all cells (though plasmacytoid dendritic cells are specialist IFN-producing cells), and the type I IFN receptor, IFNAR, is present on all tissues. IFNβ is made first, and there are many variants of IFNα.
- **Type II** IFN is IFNγ, whose receptor is IFNGR.
- **Type III** IFN is IFNλ, which signals through the IL-28R only present on epithelial cells.

Viruses can **evade** the immune response by masking PAMPs. They can evade the IFN response by:
- generally interfering with host cell gene expression and protein synthesis
- blocking IFN induction cascades by binding to or cleaving a part of it, e.g. with a protease
- inhibiting IFN signalling, such as by preventing certain phosphorylations
- blocking individual IFN-induced antiviral enzymes
- activating SOCS
- having a replication process that is insensitive to IFN

**Viral pathology**
The **damage** done by a virus is a combination of damage to infected cells by the virus and damage to infected and non-infected cells by the immune response. Note that many viruses change the immune response to increase their own replication / transmission, and this can result in inadvertent pathology.

Viruses can be resistant to the interferon-stimulated genes’ products, so more viruses are made. This can trigger an even larger cytokine response known as the **cytokine storm**, which can be fatal. For example, **H5N1** (swine flu) replicates, inducing lots of IFN and therefore TNF-α and other cytokines. However, the virus is resistant to the inhibitory effects of cytokines so replicates unchecked. Thus, it induces even more IFN and even more cytokines, resulting in immune pathology and potentially death.

**Antibody response evasion**
Evolutionary pressure exerted by antibodies drives viruses to change their antigens, **antigenic drift** (e.g. flu), or to exist as multiple serotypes, called **antigenic variation** (e.g. rhinovirus’ 20 serotypes!).

The reason that **Dengue** is particularly dangerous is that it exists as 4 different serotypes, and antibodies against a previously-contracted one can bind to a different serotype but don’t neutralize it. This leads to antibody-dependent enhancement of the virus and the classic **haemorrhagic fever**.

**Cellular immunity**
As viruses are intracellular pathogens, they are an easy target for processing and presentation by MHC. Cellular immunity is often induced to internal viral proteins which vary less than surface antigens. TAP proteins load viral peptides onto MHC. Viruses can evade this in a number of ways. For example:
- **EBV**’s EBNA1 cannot be broken down by the proteasome
- **HSV**’s ICP47 blocks TAP so processed proteins cannot be loaded
- **CMV**’s US6 stops ATP binding to TAP, thus inhibiting its action

If MHC hasn’t had a viral peptide loaded onto it, it won’t go to the cell surface. This means it can’t be presented, but it creates another problem because **NK cells** kill cells which lack MHC expression. This can be avoided by producing decoy MHC molecules to be expressed instead (e.g. **CMV** does this).
5: Parasitic infection

**Infection:** invasion of the body by, and growth of, pathogenic microorganisms.

**Disease:** a disordered or incorrectly functioning organ, part, structure, system … etc..

There can be infection without disease and disease without infection. Both can also lead to the other.

**Parasite:** an organism living in/on a host that it depends on for nutrition, and causes damage to.

There are **ectoparasites** and **endoparasites**. The latter category contains two categories of its own:
- **protozoa** are **eukaryotic, single-celled** organisms, and include:
  - **amoebae** e.g. Entamoeba histolytica, Entamoeba dispar
  - **coccidia** e.g. Plasmodium, Toxoplasma, Cryptosporidium
  - **ciliates** e.g. Balantidium coli
  - **flagellates** e.g. Trichomonas, Giardia, Trypanosoma, Leishmania
- **metazoa**, or **helminths** e.g. roundworms, flatworms, flukes

**Amoebae**
Amoebae, e.g. Entamoeba histolytica, Entamoeba dispar, can cause **amoebiasis**. This causes **dysentery** (bloody diarrhoea) and **liver abscess**. ~10% of the world is infected with E. histolytica, and it is the third most common cause of death due to parasites, after schistosomiasis and malaria. It is far more common in the tropics than in temperate climes. ~90% of infections are **asymptomatic**.

Infection occurs through **faecal-oral** spread. In the small intestine, E. histolytica **cysts** release active amoebic parasites (**trophozoites**) which invade the colon’s epithelial cells and cause flask-shaped ulcers. From there, the infection can spread via the blood to other organs such as the liver, lungs and brain. Even **asymptomatic carriers pass cysts in faeces**; a major reason for how widespread it is. Note that E. dispar is a normal commensal in the GI tract and must be differentiated from E. histolytica.

**E. histolytica’s life cycle:**

![E. histolytica life cycle diagram]

Ingestion in contaminated food and water

Mature cyst

Noninvasive infection
Cysts exit host in the stool

Endodyogeny

Excystation
One trophozoite with four nuclei emerges divides three times and each nucleus divides once to produce eight trophozoites from each cyst

Trophozoites migrate to the large intestine

Trophozoites multiply by binary fission

Immature cyst

Invasive infection through the bloodstream, infecting sites such as the liver, brain, and lungs.

One trophozoite with four nuclei emerges divides three times and each nucleus divides once to produce eight trophozoites from each cyst

Trophozoites multiply by binary fission

Immature cyst
**Coccidia**

*Plasmodium* causes *malaria*, whilst *Toxoplasma* causes *toxoplasmosis* (a mild disease for immunocompetent people but very dangerous to a fetus), and *Cryptosporidium* causes diarrhoea.

*Toxoplasma* can form cysts in tissues, mainly muscle, the brain and eyes, which may remain for life. Spread can occur via pet faeces, undercooked meat, and organ transplantation or blood transfusion. *Cryptosporidium* is spread by infected water, either drinking water or in swimming pools and so on.

**Ciliates**

*Balanidium coli* causes *balantidiasis*. It’s found globally carried by pigs, rodents, and primates. The life cycle of *B. coli* is very similar to *E. histolytica*, though there’s no mention of spread to other organs.

**Flagellates**

*Giardiasis* (traveller’s diarrhoea) is the most common water-borne protozoal infection. It is found worldwide and is caused by *Giardia lamblia*, whose flagellated trophozoites attach to duodenal or jejunal epithelium. *Giardia’s* cysts can survive chlorination so have to be filtered out of drinking water.

*Trichomonas* is another flagellate, but is transmitted sexually. The trophozoites attach inside the vagina or urethra, and cause abnormal discharge. It can be spread by secretions and urine.

*Leishmania* is also a flagellate, which causes *leishmaniasis*. See next page.
Leishmaniasis

Leishmania’s vector is the sand fly, like Plasmodium’s is the mosquito. In the sand fly, Leishmania develops into promastigotes (shown right). These move using their flagella. The promastigotes are injected into humans when the infected sand fly bites. Once the parasite has infected human cells, it retracts its flagellum, becoming an immobile amastigote. These are the form of Leishmania that an uninfected sand fly will ingest.

Sand flies are found in the warmer parts of the world, so basically everywhere except North America, Northern Europe and Asia, and at the poles. Sand flies are ~3mm long and hairy. They are smaller than mosquitoes and are silent (unlike mozzies). Only females feed on blood (to supply nutrients for their eggs). Species of sand fly, which carry different species of Leishmania, vary by region.

There are four major forms of leishmaniasis:
- visceral leishmaniasis
- localised cutaneous leishmaniasis
- diffuse cutaneous leishmaniasis
- mucocutaneous / mucosal leishmaniasis

Visceral leishmaniasis (VL), also known as ‘kala azar’ (black fever), is fatal if untreated but for every overt case there are 30-100 subclinical infections. Risk factors include malnutrition and immunosuppression (either by drugs or HIV). One species which causes it is L. donovani. Symptoms include:
- irregular fever
- weight loss
- hepatomegaly
- splenomegaly
- anaemia

First line treatment is with IM or IV sodium stibogluconate (SSG) or meglumin antimoniate. In some regions, contracting post-kala azar dermal leishmaniasis (PKDL) is common during or after treatment of a sub-clinical infection. Nodular lesions appear on the face and can spread to the rest of the body.

Localised cutaneous leishmaniasis (LCL) causes skin lesions on exposed body parts, which can be ulcerating. They are often self-healing and lead to immunity against re-infection, but can create serious disability and scars. Species causing cutaneous leishmaniasis include L. major and L. tropica.

Diffuse cutaneous leishmaniasis (DCL) causes multiple, nodular, non-ulcerating skin lesions often on the face and hands. One species which causes it is L. aethopica.

Mucocutaneous leishmaniasis (MCL), caused by L. braziliensis, affects the skin around the mouth, causing disfigurement. Mucosal leishmaniasis just destroys the mouth and lips themselves (mucous membranes), and is caused by L. infantum as well as L. major, L. tropica, and L. aethopica.

Of the latter three, the cutaneous leishmaniases, LCL is by far the most common, followed by MCL and then DCL. Treatment for can involve SSG either systemically or intra-lesion, and/or cryotherapy. Two important cell surface molecules on Leishmania are lipophosphoglycan (LPG) and gp63, a protease. They can inhibit the fusion of the phagosome and lysosome in macrophages and neutrophils,
and also inhibit activation, suppressing MHC class I and II expression and other signalling. However, as LPG, gp63, and other cell surface molecules like glycoproteins and glycoinositol phospholipids (GIPLs) are still the first molecules to come into contact with the innate immune system, they do induce APCs.

**Helminths**

The above were all protozoa. The **metazoa** category contains all the **worms** (helminths). Helminths are complex multicellular parasites. Their life cycles may involve insect vectors or intermediate hosts, but for most, humans are their definitive host. Few are zoonoses acquired from animals. The most common worm infections are **ascariasis**, **trichuriasis**, **hookworm** infection, then **schistosomiasis**. School-age children are the age group most commonly affected. There are different types of worm:

- **roundworms** (nematodes) e.g. *Ascaris, Filaria, Strongyloides, hookworm*¹
- **flatworms** (cestodes) e.g. *Taenia* (tapeworm)
- **flukes** (trematodes) e.g. *Schistosoma*

¹The two main species of **hookworm** are *N. americanus* and *A. duodenale*, found in different regions.

**Nematodes / roundworms**

*Ascaris lumbricoides* causes **ascariasis** (see right). Adult worms are ~20-30cm in length. One female can produce hundreds of thousands of eggs per day, which get passed in the faeces.

Fertile eggs embryonate and become infective after several weeks if environmental conditions in the **soil** are good (warm, moist, shaded). After infective eggs are swallowed, the larvae hatch and invade the **intestinal mucosa**. They travel via the blood to the **lungs** where they mature further for 1-2 weeks before they penetrate the alveolar walls, ascend the bronchial tree to the throat, and are **swallowed again**. Upon reaching the **small intestine**, they develop into adult worms. It takes 2-3 months from egg ingestion to having an adult female able to produce her own eggs. Adult worms can live for 1-2 years.

Ascariasis is **often asymptomatic**. Large numbers of worms may cause **abdominal pain** or **intestinal obstruction**, and can **exacerbate existing malnutrition**. Migration of larvae may cause localised reactions in various organs e.g. *Loeffler’s pneumonia*, where larvae penetrating from capillaries into the lungs causes pools of blood and dead epithelial cells to clog air spaces. This increases the patient’s susceptibility to potentially fatal bacterial infections.

**Hookworms** (see right) are about 1cm long, and attach by their ‘mouth’ to the villi of the **small intestine**. A few worms may cause no symptoms, but having hundreds can cause **bloody diarrhoea** and **anaemia** because the worms leave **open wounds** in the intestinal mucosa. This also leads to inflammation of the bowel. Terrifying.

**Trichuris trichuria**, also called **whipworm**, is used as therapy for allergy and autoimmune disease.
Lymphatic filariasis is caused by *Filaria* obstructing the lymphatic vessels, usually in a leg, leading to elephantiasis (shown right). It can also affect the arm, breast, or scrotum, with similar fluid build-up effects. Cutaneous filariasis also exists, and species like *Onchocera volvulus* in the eye cause river blindness.

Cestodes / tapeworms
*Taenia solium* from pork and *Taenia saginata* from beef can cause abdominal discomfort, diarrhoea, and weight loss. Tapeworms attach to the small intestine and can be ~3m long in adulthood.

Trematodes / flukes
The most important example of a fluke is *Schistosoma*. Eggs in water such as ponds, lakes, or canals hatch into miracidiae which penetrate suitable snails. In the snail, they develop into sporocysts which are released and become fork-tailed cercariae. Cercariae can penetrate the skin of a human in the water, upon which they shed their tail, becoming schistosomulae which migrate via the portal venous system and liver to the rectum. There they lay their eggs. The exception is *S. haematobium*, which settles in the bladder, so its eggs are expelled in the urine instead of the faeces. Eggs laid in the liver cause cirrhosis. This can lead to portal hypertension, oesophageal varices and haematemesis.

Ectoparasites
The above were all endoparasites (settled inside the body). Ectoparasites are all external and include:
- scabies (*Sarcoptes scabiei*), mites whose females burrow into the epidermis to lay their eggs
- lice, including head lice (*Pediculus capitis*, ‘nits’ are their eggs) and pubic lice (*Pthirus pubis*)